



INVESTOR IN PEOPLE

The Patent Office  
Concept House  
Cardiff Road  
Newport  
South Wales  
NP10 8QQ

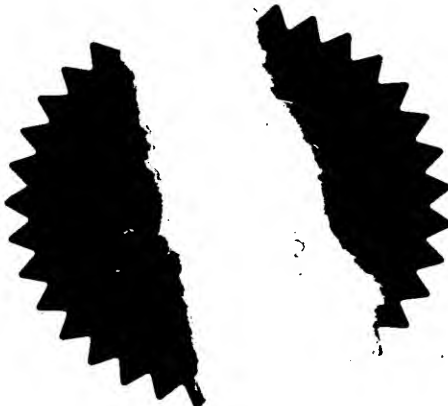
I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

I also certify that the attached copy of the request for grant of a Patent (Form 1/77) bears an amendment, effected by this office, following a request by the applicant and agreed to by the Comptroller-General.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.



Signed

Dated

21 November 2003



100

100

100

100

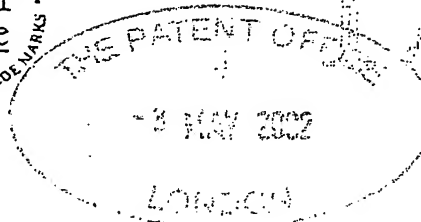
100

## Patents Form 1/77

Patents Act 1977  
(Rule 16)

## Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)



The Patent Office

Cardiff Road  
Newport  
South Wales  
NP10 8QQ

## 1. Your reference

R071458PGB

3 MAY 2002

## 2. Patent application number

(The Patent Office will fill in this part)

0210305.9

07MAY02 0110421-1 003012  
P01/7700 0.00-0210305.9

## 3. Full name, address and postcode of the or of each applicant (underline all surnames)

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

DELPHI TECHNOLOGIES, INC  
PO BOX 5052  
TROY  
MICHIGAN 48007  
USA

DELAWARE, USA

7588320001

## 4. Title of the invention

FUEL SYSTEM

## 5. Name of your agent (if you have one)

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

MARKS & CLERK  
ALPHA TOWER  
SUFFOLK STREET QUEENSWAY  
BIRMINGHAM B1 1TT

DAVID KELLIE ASSOCIATES  
FLEET PLACE HOUSE  
2 FLEET PLACE  
LONDON  
EC4M 7ET

Patents ADP number (if you know it)

18002

PSI MB 29.4.03

## 6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number

Country

Priority application number  
(if you know it)

Date of filing  
(day / month / year)

## 7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

Date of filing  
(day / month / year)

## 8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if:

Yes

- a) any applicant named in part 3 is not an inventor, or  
b) there is an inventor who is not named as an applicant, or  
c) any named applicant is a corporate body.  
See note (d))



## Patents Form 1/77

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form

Description 15

Claim(s)

Abstract

Drawing(s) 2

10. If you are also filing any of the following, state how many against each item.

Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for preliminary examination and search (Patents Form 9/77)

Request for substantive examination (Patents Form 10/77)

Any other documents  
(please specify)

11.

I/We request the grant of a patent on the basis of this application.

Signature

Date

3 MAY 2002

12. Name and daytime telephone number of person to contact in the United Kingdom

JOANNE POPLER  
MARKS & CLERK

0121 643 5881

**Warning**

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

**Notes**

- If you need help to fill in this form or you have any questions, please contact the Patent Office on 08459 500505.
- Write your answers in capital letters using black ink or you may type them.
- If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.
- If you have answered 'Yes' Patents Form 7/77 will need to be filed.
- Once you have filled in the form you must remember to sign and date it.
- For details of the fee and ways to pay please contact the Patent Office.



## FUEL SYSTEM

This invention relates to a fuel system for use in delivering fuel to a cylinder of an associated compression ignition internal combustion engine of the type provided with an after treatment device for the purpose of emission level control. The invention also relates to a method of delivering fuel to an engine.

Known fuel systems commonly include a fuel pump having one or more cam driven plungers arranged to pressurise fuel within a pumping chamber for delivery to the injectors of the associated engine. In a unit pump/injector scheme, a single plunger is driven to pressurise fuel within a pumping chamber, from where high pressure fuel is delivered to the delivery chamber of an injector located within a housing common to the pump elements. Alternatively, the pump and the injector may communicate through a separate high pressure fuel line interconnecting the pumping chamber with an injector delivery chamber.

It is a recent development in diesel engine technology to provide the engine with an after treatment device for the purpose of improving exhaust emission levels. For regeneration purposes, such devices periodically require an injection of fuel to the engine sometime after a main injection event (referred to as "late post injection"). Typically, such late post injection of fuel may be required several times for any one tank of fuel used.

It is an object of the present invention to provide a fuel system which enables this to be achieved.

According to a first aspect of the invention there is provided a fuel system for use in an internal combustion engine, the fuel system comprising;

- 2 -

a fuel pump having a pumping cycle during which fuel is pressurised to a high level within a pumping chamber for delivery to an injector, whereby the injector is arranged to provide a primary fuel injection event, and a secondary fuel injection event within the same pumping cycle, in use,

the injector including a valve needle which is engageable with a valve needle seating to control fuel delivery through an injector and injection valve control means for controlling movement of the valve needle so as to control the primary and secondary fuel injection events,

the fuel system further comprising an accumulator volume for storing high pressure fuel for delivering the secondary fuel injection quantity, and additional valve means for controlling the supply of fuel stored within the accumulator volume to the injector for the secondary injection event.

For the purpose of this specification, the phrase "secondary injection event" is not limited to an event which occurs later than a "primary injection event" in a pumping cycle, and the secondary injection event may equally occur before the primary injection event.

The fuel system is particularly suitable for use in an engine provided with an after treatment device for reducing emission levels. In such circumstances, the primary injection event takes the form of a main fuel injection event, during which a main fuel injection quantity is delivered, and the secondary injection event takes the form of a late post injection event, during which a late post fuel injection quantity is delivered, whereby the late post injection of fuel occurs after the main injection of fuel in the pumping cycle.



The after treatment device associated with the engine may be a nitrogen oxide absorber type device (a NOx absorber device), in which case the additional valve means is preferably arranged to deliver a late post fuel injection quantity which may be approximately the same as the main fuel injection quantity.

Alternatively, if the after treatment device is of the diesel particulate filter (DPF) type, the additional valve means is preferably arranged to deliver a late post fuel injection quantity which may be approximately between 5 and 20% of the main fuel injection quantity.

In one embodiment, the injection control valve means and the additional valve means may be arranged to provide a sequence of around 3 to 5 consecutive main fuel injection events, each of which is accompanied by a late post fuel injection event. Preferably, this sequence may be provided once for each tank of fuel used.

In another embodiment, the injection control valve means and the additional valve means may be arranged to provide a periodic distribution of late post fuel injection events between main fuel injection events. The late post fuel injection events may typically be provided between 3 and 5 times for each tank of fuel used by the engine. The number of late post fuel injection events will be selected according to the requirements of the engine/after treatment device specifications.

The additional valve means may conveniently take the form of an electronically operable valve, preferably an electromagnetically operable valve. In one embodiment, the additional valve means includes an electromagnetically operable actuator for switching the additional valve means between open and

- 4 -

closed states, wherein the actuator is common to the injection control valve means.

Conveniently, the fuel system may include a drive arrangement for the pumping plunger. Preferably, the drive arrangement takes the form of a cam drive arrangement including a cam having a surface with one or more cam lobe. Preferably, the cam drive arrangement includes a roller and a drive member, whereby the roller cooperates with the cam surface to impart movement to the drive member, thereby to drive the pumping plunger to perform a pumping stroke during which the plunger moves to reduce the volume of the pumping chamber.

The invention is not limited to use in administering a late post injection of fuel for the purpose of regenerating an after treatment device associated with the engine, but equally may be used to provide a pilot injection of fuel just before or just after a main fuel injection of fuel, or may be used to shape the injection rate characteristics.

For example, the injection control valve means may be arranged to provide the primary injection event at a primary fuel injection rate, and the secondary injection event at a secondary fuel injection rate which is greater than the primary fuel injection rate (i.e. a so-called "boot-shaped" injection).

According to a second aspect of the invention there is provided a method of delivering fuel to an internal combustion engine provided with an after treatment device for reducing emission levels, the method comprising;

driving a pumping plunger to perform a pumping stroke, thereby to pressurise fuel within the pumping chamber to a high level,

delivering high pressure fuel to an injector associated with the engine,

controlling an injection control valve means to move between an open state to commence a main fuel injection event and a closed state to terminate the main fuel injection event, during which main fuel injection event a main fuel injection quantity is delivered to the engine, and

moving the injection control valve means from the closed state to the open state to permit a late post fuel injection quantity to be delivered to the engine, during the same plunger pumping stroke and a period of time after the main fuel injection event, for the purpose of regeneration of the after treatment device.

In one embodiment, the method is achieved by appropriate shaping of the cam surface to ensure that the main fuel injection event is terminated prior to full plunger lift, just before the plunger rides over the peak of the cam lobe. Thus, the cam may be shaped such that there is a sufficient period at the end of the pumping stroke to charge the high pressure volume of the pumping chamber (and any interconnecting high pressure fuel passage(s)) for the late post fuel injection event, just prior to full plunger lift.

Alternatively, the late post injection event may be administered just after full plunger lift, just before or just after the plunger commences the return stroke.

Preferably, the step of providing the late post fuel injection quantity may be performed for up to 5% of main fuel injections.

- 6 -

In one embodiment, the method includes the step of providing a sequence of around 3 to 5 consecutive main fuel injection events, each of which is accompanied by a late post fuel injection event.

More preferably, said sequence is provided once for each tank of fuel used by the engine.

In another embodiment, the method may include the step of providing a periodic distribution of late post injection events between main fuel injection events.

Preferably, the late post injection events are provided several times for each tank of fuel used by the engine.

It will be appreciated that preferred and/or optional features of the first aspect of the invention are equally applicable to the second aspect of the invention.

The invention will further be described, by way of example, with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram to illustrate a fuel system in accordance with a first aspect of the invention, and

Figure 2 is a schematic diagram to illustrate an alternative fuelling method in accordance with a second aspect of the invention.

The fuel system illustrated in Figure 1 is suitable for use in fuelling an engine provided with an after treatment device for the purpose of regulating emission levels. Such devices may be of the NOx absorber type, or may be of the diesel

- 7 -

particulate filter (DPF) type, both of which are known in the art. For the purpose of regenerating such devices, it is necessary to inject a quantity of fuel into the engine some time after a main fuel injection event, commonly referred to as "late post fuel injection". Such late post fuel injection is typically required for up to 5% of main injection events.

The fuel system includes a unit fuel pump 10, the outlet 11 of which communicates through a high pressure fuel line 12 with an inlet 13 of an electronically controlled fuel injector 14. The pump 10 and the injector 14 are both controlled electronically by a control unit (not shown) which receives signals from a plurality of sensors monitoring, for example, engine speed, position and temperature. The signals supplied to the control unit by the sensors are used in controlling the operation of the fuel system to appropriately control the pressure of fuel supplied to the injector 14 and the timing at which injection of fuel to a cylinder of an associated engine takes place, as described in further detail below.

The fuel injector comprises a valve needle 16 which is slideable within a bore formed in a nozzle body 18. The needle 16 includes angled thrust surfaces 16a orientated such that the application of fuel under high pressure from the high pressure fuel line 12 applies a force to the valve needle 16 urging the valve needle 18 out of engagement with a valve needle seating to permit fuel injection into the engine.

The injector is preferably of the type in which fuel is supplied to a control chamber (not shown) from the high pressure fuel line 12, through an injector supply passage (not shown). The control chamber communicates continuously with the injector supply passage through a restriction. Fuel pressure within the control chamber is controlled by means of injection control valve means,

- 8 -

typically in the form of an electromagnetically operable injection control valve, which is arranged to control communication between the control chamber and a low pressure drain. By controlling the injection control valve to move between open and closed states, valve needle movement towards and away from the valve needle seating is controlled to provide the required fuel injection characteristics.

The unit pump 10 is of a known type, including a pump housing 20 defining a bore (not shown) within which a pumping plunger 22 is reciprocable under the action of a cam drive arrangement mounted upon an engine driven shaft and arranged to act against a return spring 24. The plunger bore defines, together with an end surface of the plunger, a pumping chamber (not shown) which communicates with the high pressure fuel line 12 through a non-return delivery valve 32 in a known manner. The non-return valve 32 is urged into an open position in which the pump outlet 11 communicates with the injector inlet 13, when fuel pressure within the pumping chamber is increased beyond a predetermined amount.

The cam drive arrangement includes a cam 26 having a cam surface 28 with one or more cam lobes, the cam surface 28 cooperating with a roller 30 of the cam drive arrangement to cause reciprocating movement of the plunger 22 within its bore through a drive member 31, typically in the form of a tappet or a shoe. In use, as the roller 30 rides over the surface of the cam 26, the plunger 22 performs a pumping cycle including a pumping stroke during which the plunger is driven inwardly within its bore to reduce the volume of the pumping chamber, and a return stroke during which the plunger is urged outwardly from its bore under the action of the return spring 24 to increase the volume of the pumping chamber. When the plunger adopts its innermost position within its

bore, and the volume of the pumping chamber is at a minimum, the plunger is said to be at "full plunger lift".

Downstream of the non-return valve 32, the high pressure line 12 communicates with a reservoir or accumulator volume 34 for high pressure fuel through a flow path 36 provided with an additional valve means in the form of a late post injection control valve 38. The late post injection control valve 38 is preferably provided with an electromagnetic actuator for switching the valve between an open state, in which the high pressure line 12 communicates with the accumulator volume 34, and a closed state in which communication between the line 12 and the volume 34 is broken. If desired, a pressure transducer 35 may be provided for measuring the pressure of fuel within the accumulator volume 34, and an output signal from the pressure transducer 35 may be fed back to the control unit for the purpose of controlling valve operation.

Fuel pumps of the type shown in Figure 1 are generally known, and are operable to control the timing of commencement of fuel pressurisation within the pumping chamber under the control of a pressure control valve (not shown). The description of such a fuel pump may be found in the Applicants co-pending European patent application EP 0957261 A2.

As the drive shaft rotates in use, the cam drive arrangement permits outward movement of the plunger under the action of the return spring 24 (the return stroke), during which fuel at relatively low pressure is drawn from a fuel reservoir through the open pressure control valve to the pumping chamber. Initially, the injection control valve of the injector 14 is de-energised and is in its closed state to ensure fuel pressure within the control chamber is sufficiently high to seat the valve needle 16, thus ensuring injection does not take place.

- 10 -

The movement of the cam drive arrangement results, subsequently, in the plunger reaching its outermost position and commencing inward movement (the pumping stroke), during which the volume of the pumping chamber is reduced. Whilst the pressure control valve of the pump remains de-energized, inward movement of the pumping plunger simply displaces fuel back to the low pressure drain reservoir, and thus does not result in pressurization of the high pressure fuel line 12. When it is determined that pressurization of the fuel line 12 should commence, a signal is applied by the control unit to the pressure control valve to cause it to close, thereby breaking communication between pumping chamber and the low pressure drain. Continued inward movement of the pumping plunger as the roller 30 rides over the cam surface 28 therefore results in pressurization of the fuel within the pumping chamber, and a point will be reached at which the delivery valve of the pump is caused to open to permit fuel flow into the high pressure fuel line 12.

As a result of the pressurization of the fuel within the high pressure fuel line 12, the fuel pressure applied to the injector 14 increases, but as the injection control valve of the injector 14 is closed, the fuel pressure within the control chamber and that applied to the thrust surfaces 16a of the valve needle 16 are substantially equal thus ensuring that the valve needle 16 remains in engagement with its seating.

Initially during the pumping stroke, the late post injection control valve 38 in the flow passage 36 is in its open state to permit pressurised fuel in the line 12 to flow into the accumulator volume 34. When fuel pressure within the accumulator volume 34 reaches the required level for late post injection, as measured by the pressure transducer 35, the late post injection control valve 38 is closed to terminate flow into the volume 34, as described further below.



- 11 -

When it is required to commence a primary (main) injection of fuel, for which a main fuel injection quantity is injected into the engine, the electromagnetic actuator of the injection control valve is energised causing the injection control valve to open. Fuel is therefore able to flow from the control chamber to the low pressure drain such that fuel pressure within the control chamber falls, thereby reducing the magnitude of the force urging the valve needle towards its seating and permitting the valve needle 16 to lift under the action of the fuel acting upon the thrust surfaces 16a. Such movement of the valve needle 16 permits fuel to flow past the seating to one or more injector outlets, and through the outlet(s) to be injected to the engine cylinder.

When the desired quantity of fuel has been delivered to the engine during the main injection event, the injection control valve is closed to increase fuel pressure within the control chamber. The magnitude of the force urging the valve needle 16 towards its seating is therefore increased, until a point is reached beyond which the valve needle 16 returns into engagement with its seating, thus terminating the supply of fuel to the engine cylinder. It will be apparent from the description hereinbefore that the operation of the injection control valve of the injector controls the timing at which fuel injection takes place.

For the purpose of regenerating the after treatment device associated with the engine, it is necessary to provide a secondary injection of fuel late in the pumping cycle, as described previously. Preferably, this is required when engine position is between  $20^\circ$  and  $180^\circ$  after the main injection event, and more preferably when it is around  $30^\circ$  after the main injection event. The desired injection timing range and the peak injection pressure are determined by appropriate shaping of the cam profile, but this can present a problem in known fuel systems as the cam profile shape limits the fuelling period. The

- 12 -

requirement for a late post injection of fuel after the main injection cannot therefore be accommodated in known schemes.

The present invention overcomes this, however, by providing the accumulator volume 34 and the additional late post injection control valve 38. The cam surface 28 is shaped such that, at the end of the main injection event when the injection control valve is moved to its closed state to reseal the valve needle 16, the plunger is only part way through its pumping stroke, and so pressurisation of fuel within the pumping chamber continues after the main fuel injection event has terminated. High pressure fuel thus continues to flow into the high pressure line 12, and hence into the accumulator volume 34, until such time as the late post injection control valve 38 is closed to trap high pressure fuel within the volume 34. Switching of the late post injection control valve 38 into its closed state is controlled by means of the control unit in response to the output signal from the pressure transducer when fuel pressure within the accumulator volume 34 reaches the required level.

When it is desired to inject the late post fuel injection quantity, the late post injection control valve 38 is opened under the control of the control unit, therefore permitting a further flow of high pressure fuel to the injector 14. At the same time the injection control valve is energised once more to cause the valve needle 16 to lift, thereby to permit the late post injection of fuel into the engine.

Inward movement of the pumping plunger continues until the plunger reaches its innermost position within its bore and the volume of the pumping chamber is at a minimum, after which the plunger commences outward movement under the action of the spring 24 acting in combination with any residual fuel pressure within the pumping chamber. The late post injection of fuel may

- 13 -

preferably be provided when the plunger is close to or just after full plunger lift. This includes, for example, providing the late post injection of fuel when the plunger is performing its return stroke. When it is desired to terminate the late post injection of fuel, both the late post injection control valve 38 and the injection control valve are moved to their closed positions.

It will be appreciated that, as the plunger commences its return stroke and fuel pressure within the pumping chamber is reduced, the non-return valve 32 is caused to close under the force of high pressure fuel in the line 12. Thus, flow of high pressure fuel from the accumulator volume 34, back through the line 12 to the pump is prevented, even if the late post injection control valve 38 is opened.

The fuel system in Figure 1 may be operated in an alternative way, by controlling the late post injection control valve 38 such that the accumulator volume 34 is filled gradually over a series of pumping cycles, rather than by filling the volume 34 completely during one cycle before the main injection takes place.

As an alternative scheme (not shown) to that shown in Figure 1, the late post injection control valve 38 need not be provided with an actuator, but may be hydraulically operable in dependence upon fuel pressure within the accumulator volume 34 and the passage 36 (and hence the high pressure line 12).

In a further alternative scheme (not shown) to that shown in Figure 1, the late post injection valve 38 and the injection control valve need not be provided with separate actuators, but may be configured to share a common actuator

- 14 -

which is operable under the control of the control unit to control the respective timing of main and late post injection.

In practice, it may only be necessary to provide the injector associated with one cylinder of the engine with the late post injection control valve 38 and the accumulator volume 34 for the purpose of administering the late post injection of fuel.

The fuel system is not limited to use in administering a late post injection of fuel for the purpose of regenerating an after treatment device associated with the engine, but instead may be used to provide a pilot injection of fuel just before or just after a main fuel injection of fuel. For example, the invention may be used to provide a close-coupled post injection, shortly after the main injection of fuel.

Alternatively, the invention may be used to shape the injection characteristic of a main injection event, for example by providing a primary fuel injection event at a primary fuel injection rate, and a secondary fuel injection event at a secondary fuel injection rate. If the secondary fuel injection event is greater than the primary fuel injection rate, the injection event has a so-called "boot-shaped" injection characteristic. In this embodiment, the primary and secondary injection events are sequential (i.e. back to back) and effectively form a single injection event having a first stage low injection rate and a second stage higher injection rate.

Referring to Figure 2, in a further alternative embodiment the late post injection control valve 38 and the accumulator volume 34 may be deleted. Instead, the injection control valve alone is operable to provide both the main injection of fuel and the late post injection of fuel. This is achieved by shaping

- 15 -

the cam profile to ensure the plunger performs the remainder of its pumping stroke after the main injection event is terminated. Once the main injection event has been terminated by closing the injection control valve, fuel pressurisation within the pumping chamber continues until the end of the pumping stroke. During the remainder of the pumping stroke, the injection control valve is re-opened to commence the late post injection of fuel and is closed when the desired quantity of fuel has been injected. Alternatively, the injection control valve may be re-opened after full plunger lift to provide the late post injection of fuel.

The embodiment of the invention described with reference to Figure 2 is particularly suitable for applications where the required late post injection fuel quantity is relatively small, for example around 10% of the main fuel injection quantity. Such late post injection fuelling amounts are particularly suitable for use with DPF type after treatment devices.

For applications where a relatively large late post injection fuel quantity is required, for example volumes approaching the main fuel injection quantity, it may be more appropriate to use the embodiment shown in Figure 1. In particular, this embodiment is suitable for use in engines provided with an NOx absorber type device.

It will be appreciated that the fuel system in accordance with the invention may include a fuel pump in which the quantity of fuel supplied to the pumping chamber is metered to permit control of the fuel injection pressure, rather than by means of a pressure control (spill) valve.



1/2

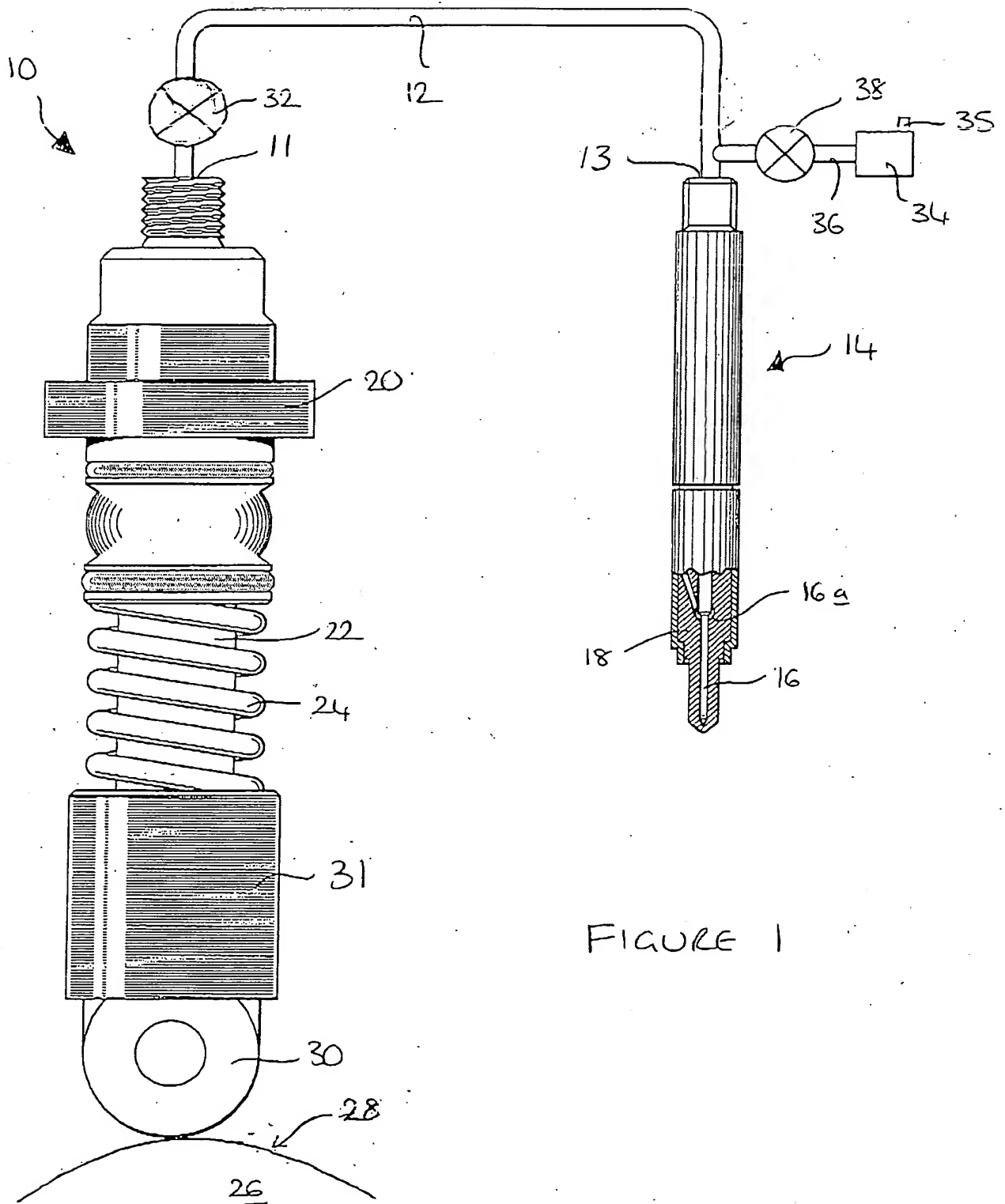


FIGURE 1





2/2

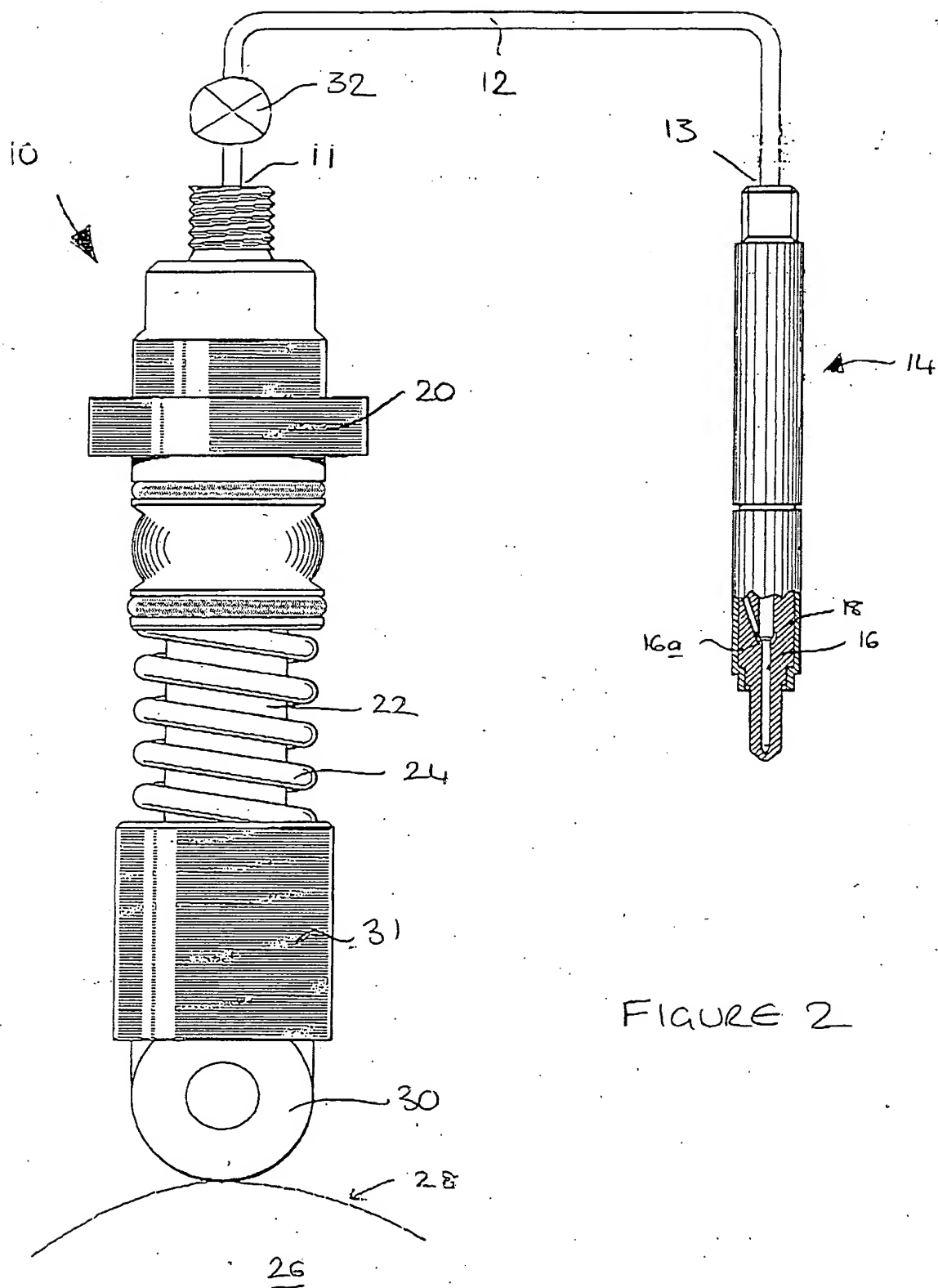


FIGURE 2

